EVAPORATION IN THE EASTERN CARIBBEAN

By C. L. RAY

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Dependable mean values of evaporation may be had, as a rule, from a comparatively short period of observations, namely 10 years, more or less. The reasons are obvious: The primary influences affecting evaporation are temperature, vapor pressure, and wind velocity under 20 miles per hour, meteorological factors with a greater tendency to repeat themselves by months or seasons than is true of rainfall. This is true in greater degree in the latitude of the eastern Caribbean than elsewhere, due to the steadiness of the easterly "trades" throughout the year and the uniformity of the temperature. The stations considered in the present paper are San Juan, P. R., lat. 18° 29′ N., period of record, 1917–1930; St. Croix, Virgin Islands, lat. 17° 46′ N., 1920–1930; and Kingston, Jamaica, lat. 18° 1′ N., 1924–1930.

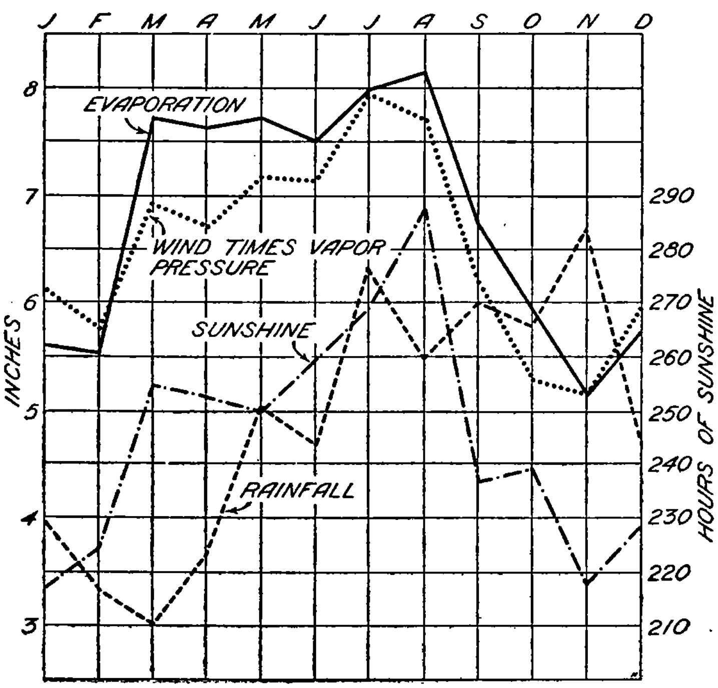

FIGURE 1.—San Juan, P. R. Evaporation (1917-1928) and related factors

At San Juan, 48 feet above mean sea level, the equipment consists of the standard evaporation pan, still well, and gage, of type similar to that in use in the continental United States since 1916. Daily observations at 8 a. m., E. S. T., include the 24-hour evaporation, rainfall, dry and wet bulb temperatures, hours of sunshine, and wind movement. The anemometer is placed at the surface of the water. Records of the average evaporation together with related data appear in Table 1, covering the three stations mentioned. In Figs. 1 and 2, graphs of the San Juan and St. Croix record are based upon Table 1, except for the omission of the years 1929–30 from the San Juan averages to allow for a comparable time period of wind mileage.

Referring to the monthly and annual values (not included in the published text), the maximum annual evaporation occurred in 1917, amounting to 88.988 inches, the secondary maximum in 1918, 87.724 inches. Wind mileage in 1917 and 1918 was between 47,000 and 49,000 miles, in 1917 being the second highest mileage on record and in 1918 the third greatest. The extreme maximum mileage occurred in 1922, exceeding 51,000 miles, during which year evaporation amounted to 82.133 inches. The year of least evaporation was 1930 (71 inches) for which period exact wind movement at the ground level is not available. The second and third lowest evaporation years were 1925 and 1927 during which occurred the extreme minimum and third lowest mileage. The effect of the wind factor is thus well defined in most instances. The maximum monthly evaporation occurred in July, 1917, amounting to 10.089 inches, the maximum wind mileage also occurring in the same month (6,323 miles); the least evaporation occurred in November, 1918, 3.999 inches, comparing with the low wind movement of 1,895 miles.

In the graph, Fig. 1, supplementing the evaporation and rainfall is shown the trace of monthly wind movement times the vapor pressure deficit, using the dry bulb and dew point vapor pressures in obtaining the latter value. A trace of the monthly variation in hours of sunshine is likewise charted. Both rather closely parallel the line of evaporation through the year. In the equation of Fitzgerald (MONTHLY WEATHER REVIEW, 1904, Evaporation Observations in the United States, by H. H. Kimball) $E = 0.3984\ (e_s - e_d)\ (1 + .0208W)$ where $e_s - e_d$ equals the vapor pressure deficit and W the wind mileage at the surface of the water, respectively, we obtain an evaporation some 25 per cent in excess of the measured readings at San Juan. The monthly values for this equation are included at the foot of Table 1. The rainfall totals at the station exceed evaporation in November, practically balance it in October, and are markedly below it through the other months. The greatest difference occurs in March with 4.6 inches excess of evaporation over rainfall.

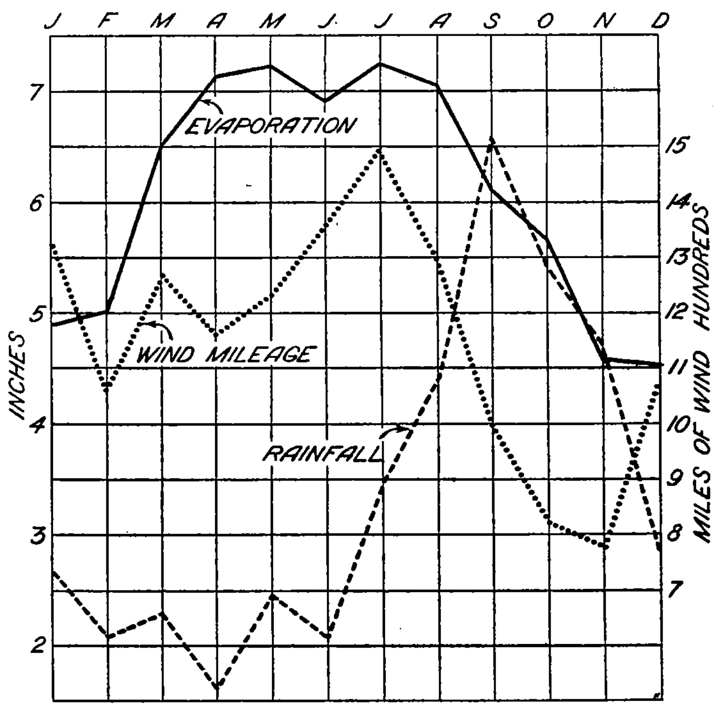

FIGURE 2.—St. Croix, Virgin Islands. Evaporation (1920-1930) and related factors

The Christiansted, St. Croix, Virgin Islands, station is maintained by the Weather Bureau as a cooperative station. It is not equipped with a sunshine recorder, nor are readings made of the wet-bulb temperature, vapor pressure, or humidity, but otherwise it is of the standard evaporation type, readings being made daily, including dry temperature, and wind mileage at the water level. Referring to Table 1 it will be noted that extreme monthly and annual values agree in general with the extremes at San Juan. Uniformly lower evaporation amounts, compared with San Juan, are accounted for largely, it would appear, by the lower wind movement. The elevation of the station is 25 feet above mean sea level, the lower wind velocities evidently due to local peculiarities of topography and exposure. The maximum evaporation at the station is registered as a rule in July, the minimum in November and December. The extreme maximum wind mileage occurs in July, the extreme minimum in November. Rainfall exceeds evaporation in September and November, approximately equals it in October, while falling well below in the remainder of the year. Fig. 2 shows the graphical picture of St. Croix evaporation over the 11-year period.

At Kingston, Jamaica, the data consist of monthly and annual measurements of evaporation over a period of seven years (1924 to 1930), including mean temperature and rainfall. The mean annual rainfall is less than 25 inches. Kingston is 59 feet above mean sea level. Wind movement is comparatively lower than that obtaining at San Juan and probably more nearly comparable to conditions at St. Croix. The vapor pressure deficit as indicated from the records available for a single year, 1901, show higher values than occur at San Juan, as would be supposed, in harmony with higher temperatures and a generally drier climate. Comparing the monthly values of the vapor pressure deficit for the year 1901 with the average monthly figures of evaporation (seven years), we find, as would be expected, extreme maximum evaporation values occurring in April and May, in coincidence with markedly larger vapor pressure deficit in those months. In Fig. 3 comparative data for the seven years (1924–1930) are given for Kingston, St. Croix, San Juan, and Balboa Heights, Canal Zone. The influence of the dry winter period at Panama is shown in the high evaporation values during the months of January to March, inclusive.

The excessive evaporation in the eastern Caribbean area is of course quite largely the result of the steady trade winds throughout practically all the year and the long daily periods of sunshine and high temperatures. The loss of moisture from land areas would be a serious problem for agriculture but for the frequent rains that occur in much of this section. In Porto Rico droughts are not generally of severity except on the south side of the island. The mountainous interior, extending from east to west, separates the area on a 70-30 basis, moisture-bearing winds leaving the great part of their precipitation on the 70 per cent northern side with consequent normally light rainfall south of the divide. The hurri-

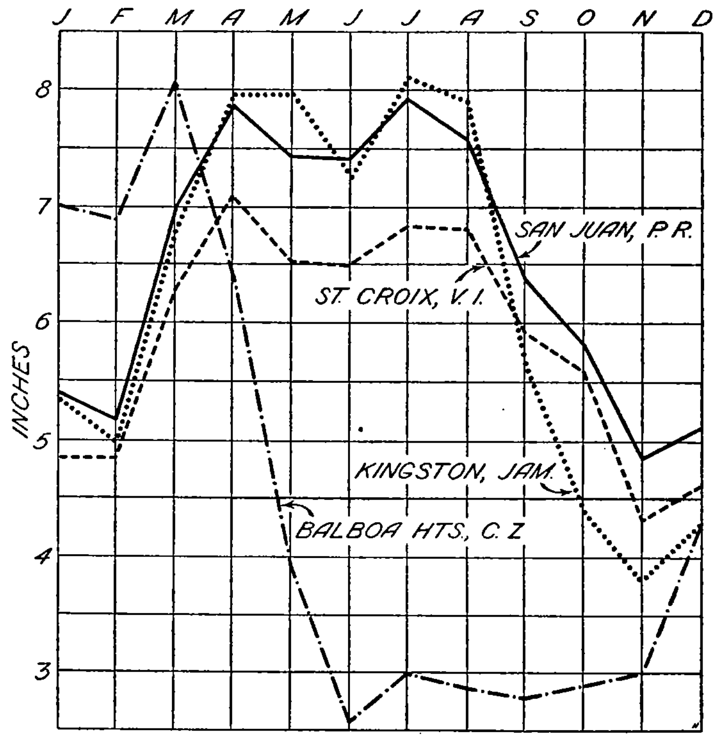

FIGURE 3.—Evaporation (1924–1930) San Juan, P. R., St. Croix, Virgin Islands, Kingston, Jamaica, and Balboa Heights, Canal Zone

cane season frequently proves a boon to the latter portion of the island if not actually extending its influence farther north. Thus, tropical storms, passing to the south of Porto Rico, often result in beneficial rains on the south side of the island without damaging winds affecting the area. Irrigation however is the main dependence through much of the south portion. Evaporation is probably considerably greater than in the northern part, due to the drier atmosphere, greater amount of effective sunshine and higher temperatures.

TABLE 1.—*Evaporation and related factors*

SAN JUAN, P. R. (1917-1930)

[Lat. 18° 29′ N., long. 66° 7′ W.]

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Evaporation	5. 558	5. 533	7. 615	7. 848	7. 743	7. 427	8. 143	8. 053	6. 615	5. 870	5. 081	5. 462	80. 948
Wind mileage	3, 975	3, 397	4, 089	3, 567	3, 401	3, 407	4, 322	3, 801	2, 561	2, 106	2, 366	3, 723	40, 716
Rainfall (inches)	4. 11	3. 15	2. 90	3. 32	5. 12	4. 65	5. 74	5. 50	5. 95	5. 41	6. 37	4. 64	56. 86
Mean temperature	74. 5	74. 5	75. 0	76. 2	78. 6	79. 3	79. 6	80. 2	80. 2	79. 6	78. 0	75. 9	77. 6
Vapor pressure deficit	. 158	. 160	. 211	. 230	. 248	. 245	. 237	. 248	. 237	. 218	. 198	. 177	
Sunshine hours	218	224	254	252	249	259	269	288	237	239	218	228	
Evaporation computed [1]	7. 025	6. 322	10. 049	9. 591	10, 097	9. 611	11. 361	11. 036	7. 806	6. 500	6. 256	7. 399	103. 053

[1] From equation of Fitzgerald.

ST. CROIX, VIRGIN ISLANDS (1920-1930)

[Lat. 17° 46′ N., long. 64° 45′ W.]

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Evaporation	4. 779	5. 005	6. 535	7. 202	7. 241	6. 909	7. 249	7. 098	6. 141	5. 731	4. 550	4. 537	72. 977
Wind mileage	1, 312	1, 046	1, 270	1, 172	1, 230	1, 364	1, 499	1, 302	1, 009	820	792	1, 082	13, 898
Rainfall	2. 70	2. 10	2. 31	1. 62	2. 40	2. 00	3. 34	4. 35	6. 59	5. 50	4. 72	2. 83	40. 46
Mean temperature	75. 9	75. 4	76. 0	77. 6	79. 6	80. 9	81. 4	81. 6	81. 1	79. 9	78. 2	76. 6	78. 7

KINGSTON, JAMAICA (1924-1930)

[Lat. 18° 1′ N., long. 76° 48′ W.]

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Evaporation	5. 463	4. 997	7. 020	7. 987	7. 920	7. 289	8. 121	7. 911	5. 457	4. 377	3. 757	4. 324	74. 623
Rainfall	0. 37	0. 69	0. 42	0. 94	1. 78	0. 63	1. 14	4. 39	3. 30	6. 00	3. 25	0. 99	23. 90
Mean temperature	76. 6	76. 3	77. 4	78. 4	80. 3	81. 4	81. 8	81. 7	81. 1	80. 1	79. 0	77. 2	78. 7

THE PIONEER METEOROLOGICAL WORK OF ELIAS LOOMIS AT WESTERN RESERVE COLLEGE, HUDSON, OHIO, 1837–1844

By ERIC R. MILLER

[Weather Bureau Office, Madison, Wis.]

In the spring of 1836 Elias Loomis (1811–1889), who had been a tutor at Yale, was appointed professor of mathematics and natural philosophy in Western Reserve College, one of the institutions acting as hosts for the meeting of the American Meteorological Society at Cleveland in 1930. Western Reserve College had been founded in 1826 at Hudson, Ohio, about 20 miles southeast of Cleveland, as a sort of Yale in Ohio by the Connecticut people who had first settled the region.

Loomis's salary was to be $600 per annum, but there was an economic depression in progress then as now, so that so much of his salary as was not paid in kind remained in arrears, and when he left Hudson the college offered to deed him some of its unimproved lands (**1**). He was allowed to spend the first year of his professorship in Europe, where he attended the lectures of Arago, Biot, Dulong, Poisson, and Pouillet in Paris, and bought apparatus there and in London, but did not have money enough to go to Germany. In the autumn of 1837 he returned to Hudson to teach and investigate for the next seven years. The chief objects of his researches were terrestrial magnetism, auroras, and storms.

Intense interest in storms had been aroused by the publications of Redfield, Espy, Dove, Reid, and Piddington, of whom Redfield and Espy had become involved in a hot controversy over the air circulation in tropical cyclones (**2**). To put the rival theories to the test of experiment, Loomis set about collecting all available data "on the storm which was experienced throughout the United States about the 20th of December, 1836," as the title of his paper runs (**3**). This storm was selected because it occurred within a period recommended by Sir John Herschel for hourly meteorological observations. The extent to which Americans were then cooperating in international meteorology is indicated by all of the phenomena having been recorded hourly at eight stations—Baltimore, New York, Albany, Flushing, New Haven, Gardiner, Montreal, and Quebec. Loomis obtained barometer readings from 27 stations, and other information from stations distributed over most of the country east of the Rocky Mountains, as well as from Bermuda, the West Indies, and from a ship on the Pacific coast.

He mapped this storm at 6-hour intervals, studying the pressure, temperature, wind direction and velocity, and precipitation. The center passed north of all of the observers, but he made a remarkable study of the phenomena of the cold front, of which his paper contains an isochronal map showing how it swept across the country. To illustrate the lines on which he attacked his problem, the following is quoted from this paper:

> But how is it possible for two winds not far separated from each other to blow violently toward each other for hours and even days in succession? Let us make a simple numerical estimate. The wind blew from the northwest at least 40 miles per hour. This gives a progress due east of more than 28 miles per hour, and is fully equal to the average progress of the barometric minimum. The atmospheric wave, then, progressed with not far from this velocity with which the wind was observed to blow, but in order to allow an opportunity for this onward progress, the wind in advance of the wave must retire, and that with the same velocity with which the northwest wave approaches. * * * The conclusion is inevitable that the northwest wind displaces the southeast wind by flowing under it. * * * The southeast current found its escape by ascending from the surface of the earth. Having quit the surface, it might either flow on in its first direction over the northwest current, or it might be driven back over the southeast current, or both of these motions might exist simultaneously. When we come to consider the cause of the rain, we shall be able to judge of the probability of these several suppositions.

After discussing radiation, advection, mixing, and "air suddenly transported into elevated regions" he observes that "the fourth cause of precipitation must be allowed to be by far the most efficient of all."

> Snow and hail (ice pellets?) did fall at nearly all of the northern stations after the northwest wind set in, but the amount was small, much less than must necessarily result if the entire southerly